SUBARCSECOND TELESCOPE AND BALLOON EXPERIMENT

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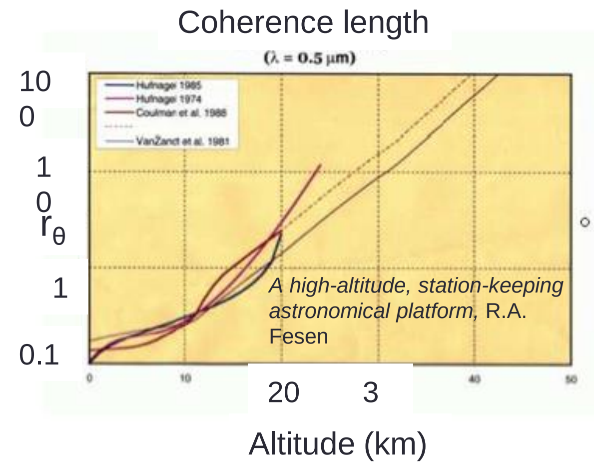
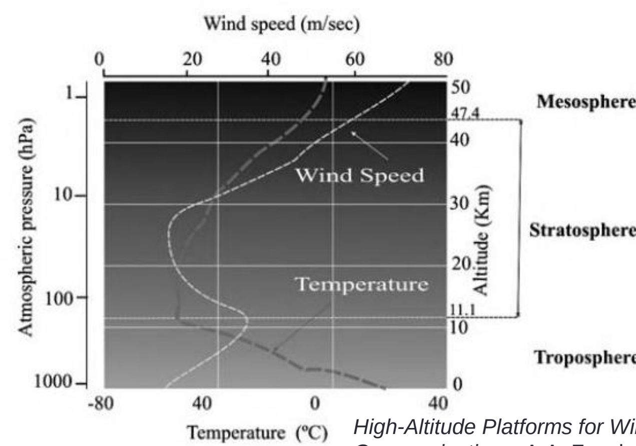
Why are HABs so Desirable?

- At the balloon altitude (>25 km) the environment is near space-like
  - Offers imaging nearly free of atmospheric degradation (atmospheric seeing)
    - Low wind speeds
    - Large coherence lengths (>8m @ 25km altitude)
  - Offers imaging in spectral bands completely blocked by the atmosphere for ground based observations
- The cost of a balloon mission is much less than a space mission
- One or more such missions flown per year
  - Attractive for scientists in lean budget times



A high-altitude, station-keeping astronomical platform, R.A. Fesen



High-Altitude Platforms for Wireless Communications, A.A. Zavala et.al.

Environmental Challenges

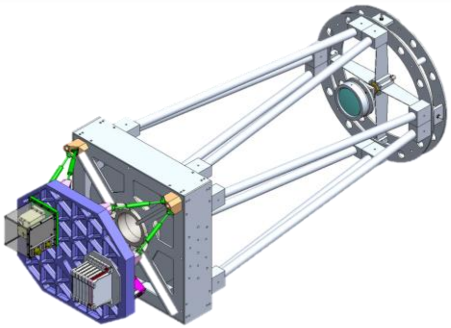
- Thermal
  - Aberrations and misalignments
  - Difference between STABLE hot and cold cases was ~80C
- Vibrational
  - Motors and reaction wheels with high frequency content
  - STABLE closed loop system with high bandwidth (~50Hz)

BIT-STABLE Overview

Attitude Rate Sensor
(JPL- Balloon Initiative)

Camera
(University of Durham, UK)

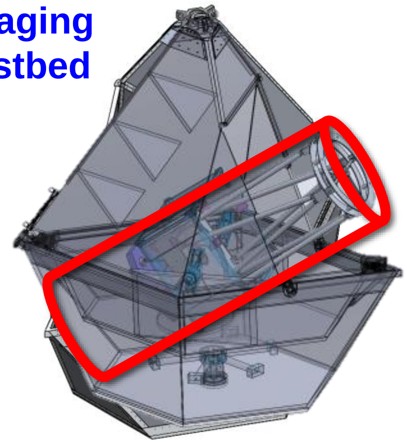
Fast Steering Mirror



Sub arcsecond Telescope And BaLloon Experiment

STABLE Payload, 0.1 arc sec
(JPL)

Balloon-borne Imaging Testbed



BIT Gondola, 2 arc sec
(Univ. of Toronto)

11MCF balloon
(CSA/CNES)

Ground Station & MOC
(CSA/CNES)

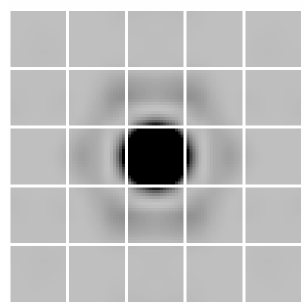
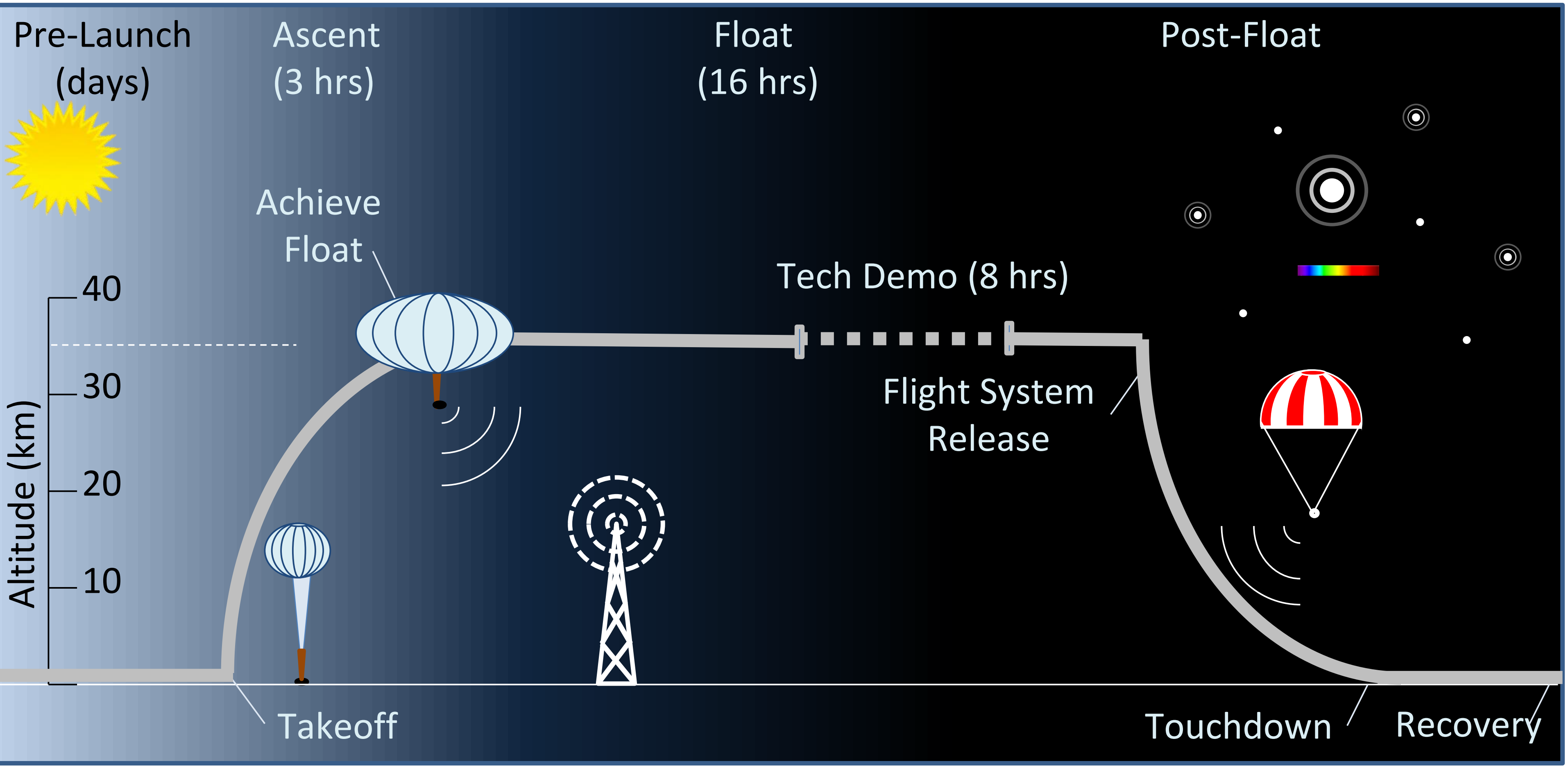


Image of PSF
(JPL)

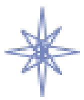
BIT-STABLE Mission Concept



STABLE Objectives

STABLE is the payload/fine control stage for a technology demonstration that will demonstrate subarcsecond pointing stability from a balloon platform for applications to balloon-borne astronomy.

- Demonstrate 0.1 arcsec stability for at least 60 seconds (1-σ per axis), assuming a 2 arcsecond outer stage

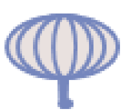


- Using a point source of light

- In the 400-900 nm band

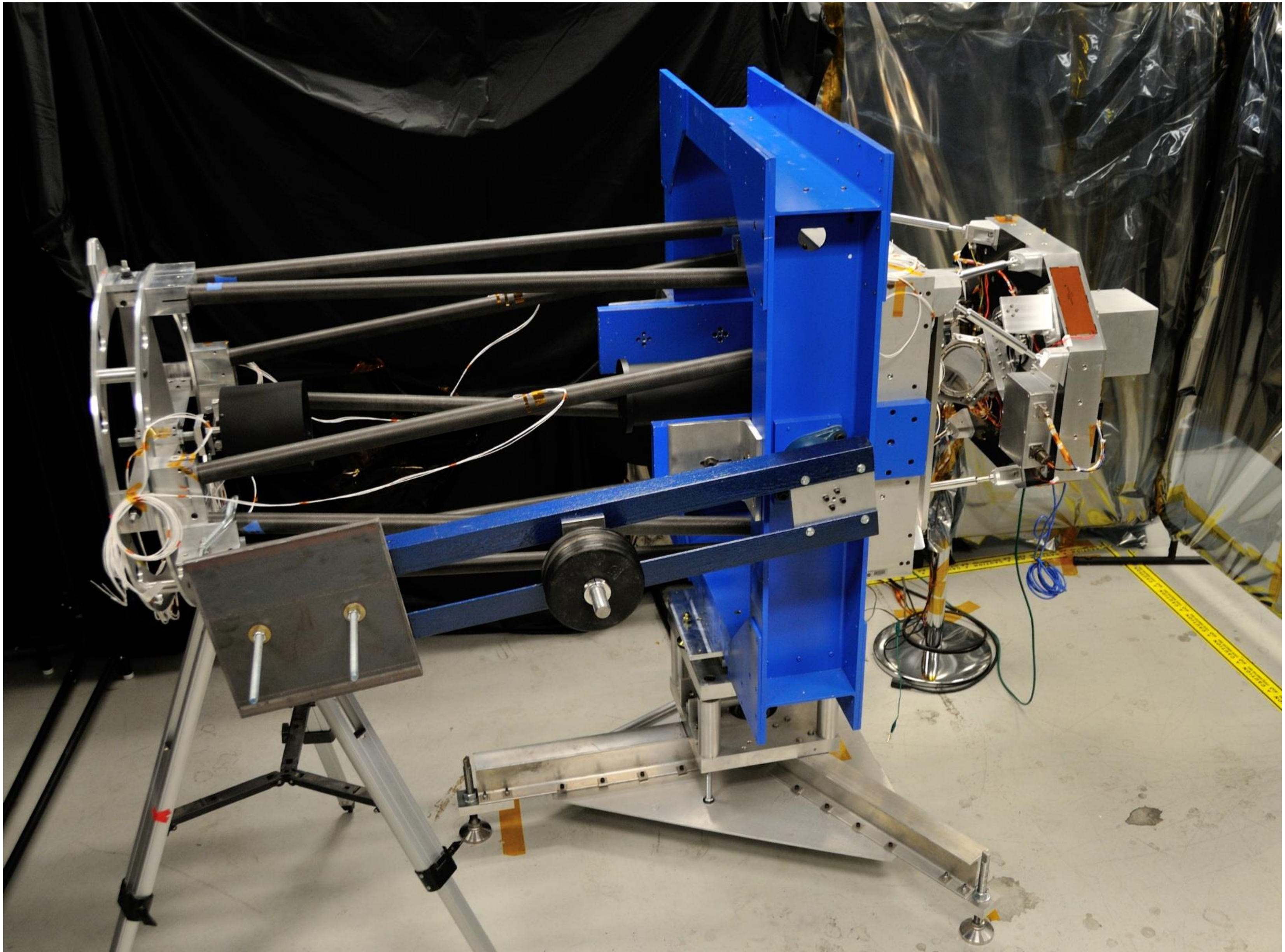
$$\mathrm{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}}$$

- With an SNR less than or equal to 25

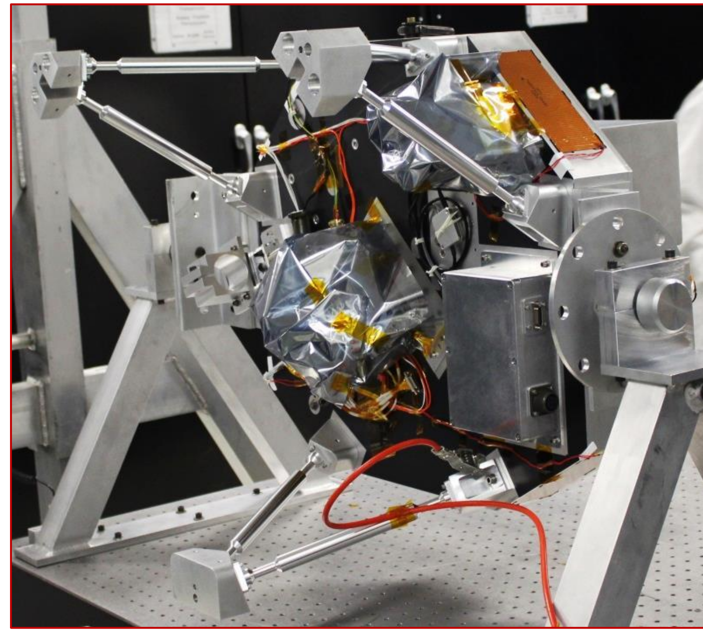


- On a balloon-borne platform above an altitude of 25 km.

STABLE Hardware

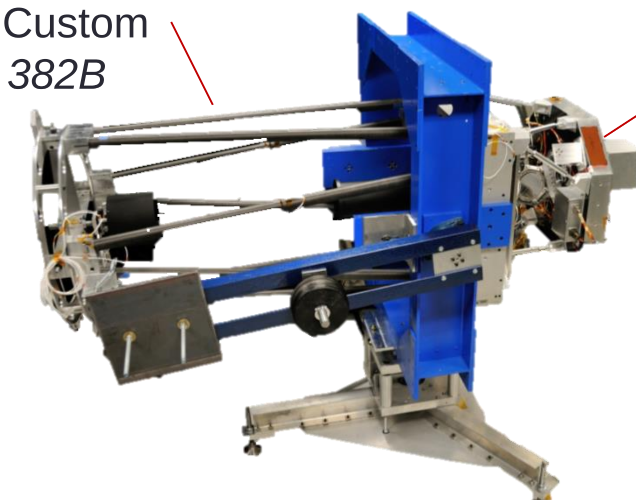


STABLE Hardware

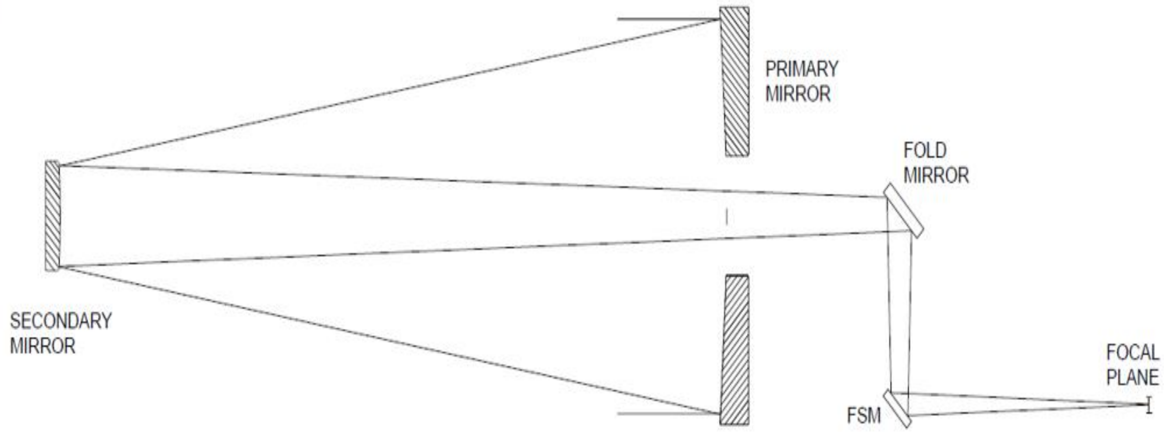


<u>Telescope (TEL)</u>
Equinox Interscience, Custom
PDM: Mike Borden, 382B

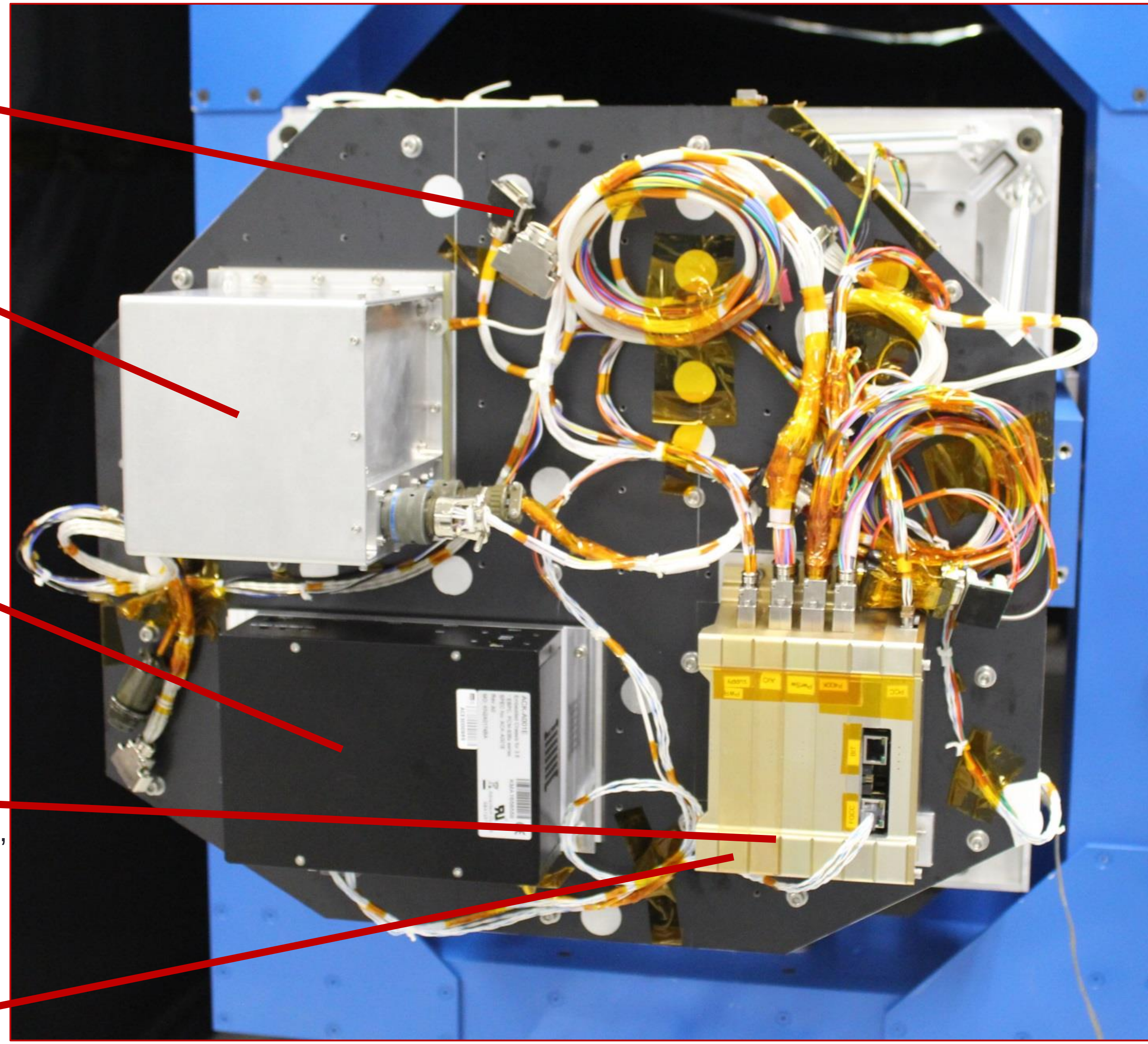
Integrated Optical Bench Assembly (IOBA)



Telescope Design



IOBA Components



Harness (HRN)
JPL In-House, John Maciejewski, 349D
PDM: Carson Umsted, 349D

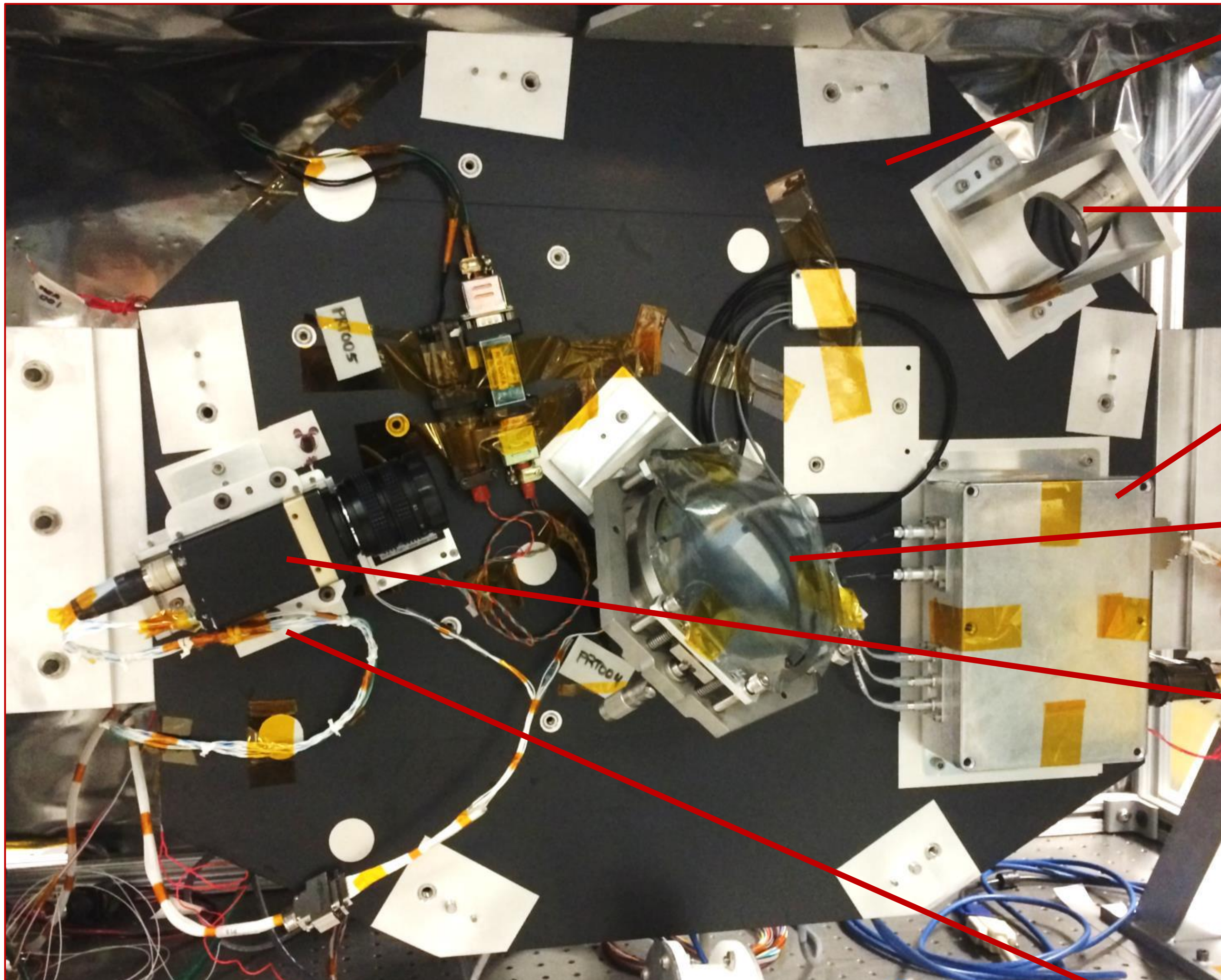
Attitude Rate Sensor (ARS)
JPL's Balloon Initiative (Kurt Liewer)
Applied Technology Associates Multi-Axis ARS Dynapak
PDM: Herrick Chang, 3443

Fine Guidance Camera Computer (FGCC)
Advantech PCM-9363, ACK-A001E chassis
PDM: Carson Umsted, 349D

Command and Data Handling Assembly (CDH),
SpaceMicro P400, ADC/DAC, Ethernet, Power Card
PDM: Carson Umsted, 349D

Power Distribution Unit (PDU),
PCC: JPL In-House,
PSC: SpaceMicro
PDM: Carson Umsted, 349D

IOBA Components



Black Kapton Tape (THR)
JPL In-House
PDM: Hared Ochoa, 353K

Fast Steering Mirror (FSM)
Physik Instrumente Actuator S-330
Edmund Optics Mirror 64-019 Custom
PDM: Mike Borden, 382B

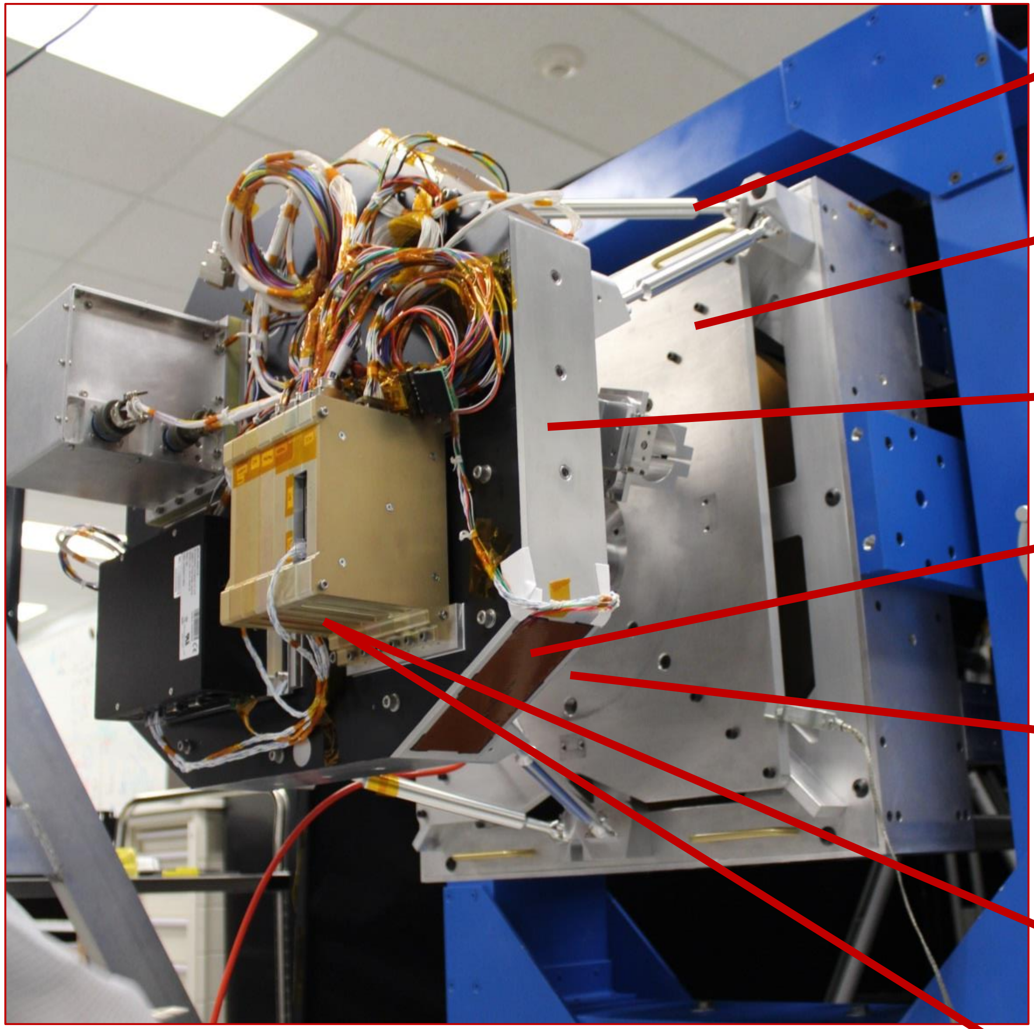
FSM Electronics (FSM ELEC)
JPL In-House Chris Shelton, 383F
PDM: Herrick Chang, 3443

Fold Mirror (FDM)
JPL In-House SIM Testbed
PDM: Mike Borden, 382B

Fine Guidance Camera (CAM)
University of Durham,
(Richard Massey)
Basler A2320
PDM: Herrick Chang, 3443

Refocusing Stage (RFS)
Zaber Technologies Inc.
T-LSM050A-SV1
PDM: Mike Borden, 382B

IOBA Components



Bipod Mount to Telescope
JPL In-House
PDM: Mike Porter, 382B

Telescope Stiffener Plate
Equinox Interscience,
JPL Design Modifications
PDM: Mike Borden, 382B

Optical Bench Assembly (OBA)
JPL In-House
PDM: Mike Porter, 382B

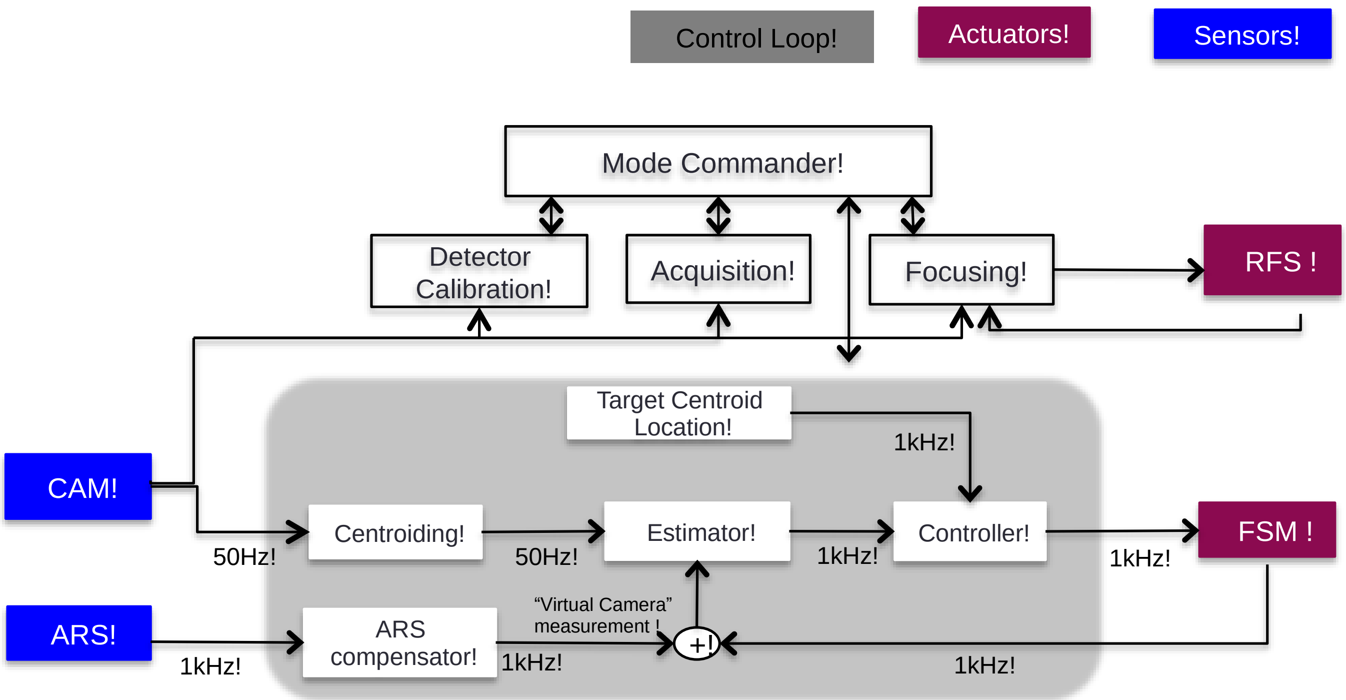
Heater Assembly 1&2
MINCO Polyimide Thermofoil
Honeywell 3200 Series Thermostats
PDM: Hared Ochoa, 353K

Temperature Sensors (PRTs)
Honeywell HRTS PRTs
Ohmite 43F7K5E 7.5 kilo-ohm Resistors
PDM: Hared Ochoa, 353K

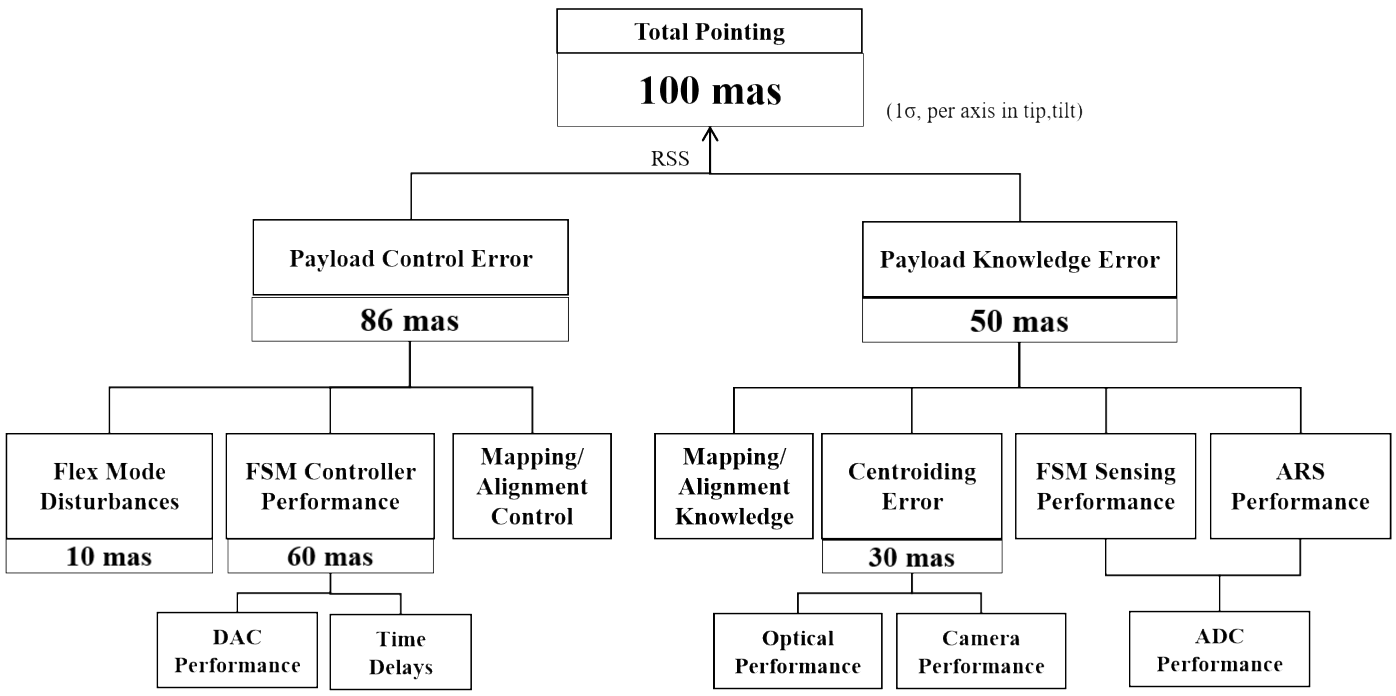
Flight Software (FSW)
JPL In-House
PDM: Aadil Rizvi, 349G

Pointing Control Algorithms (PCS ALG)
JPL In-House
PDM: Milan Mandic, 3443

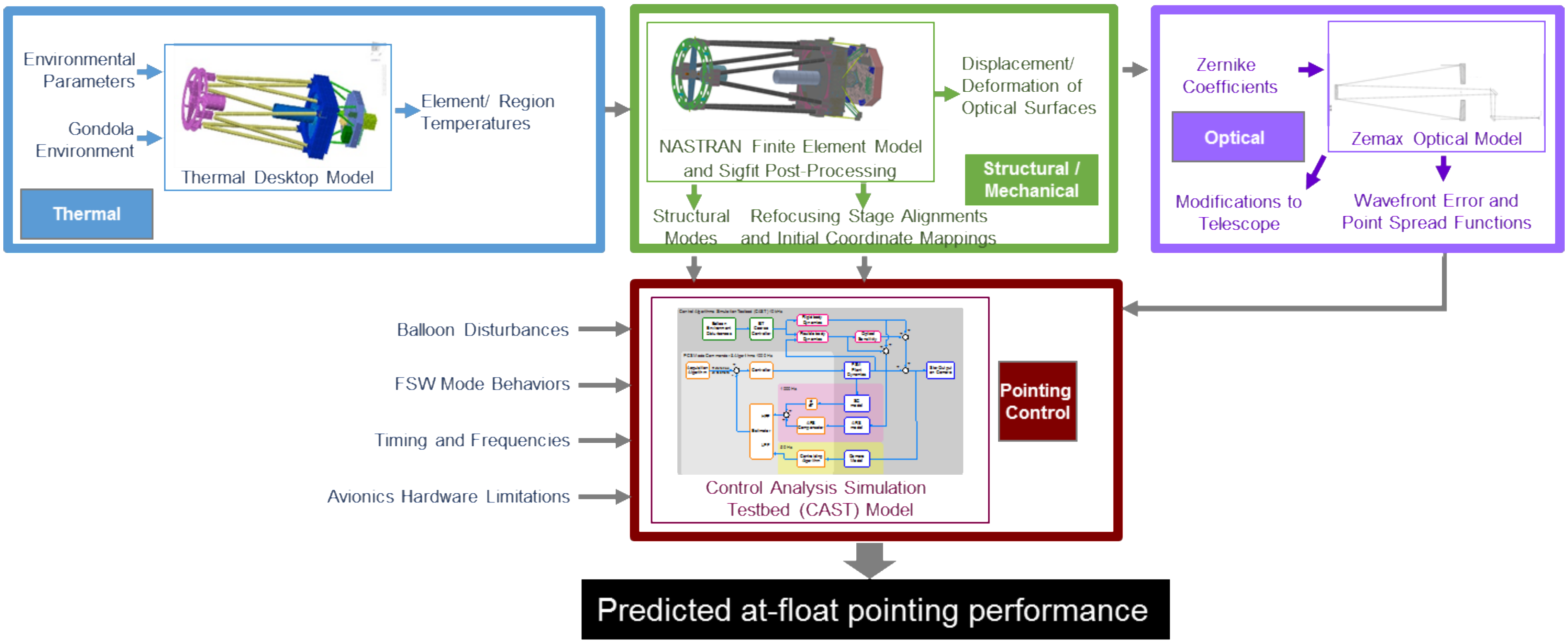
Control Loop



Error Budget



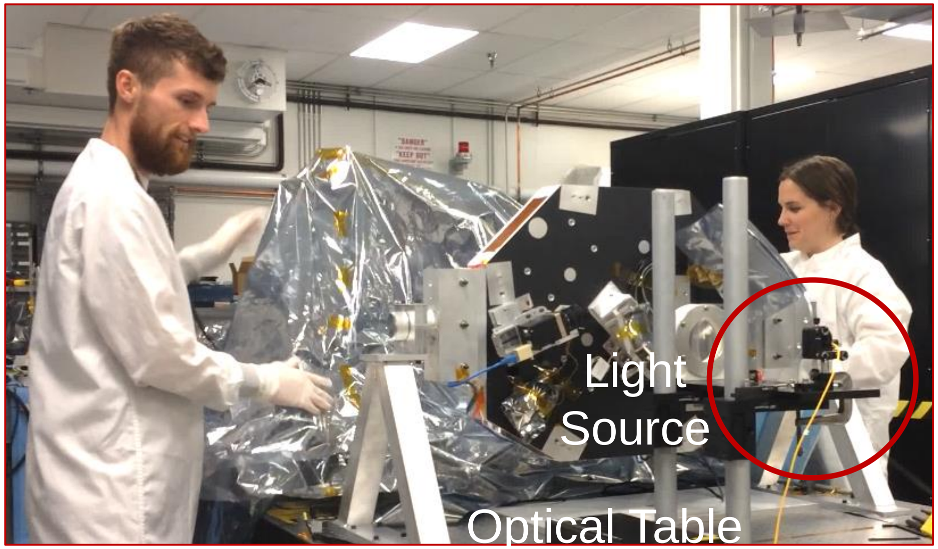
STOP Analysis Pipeline

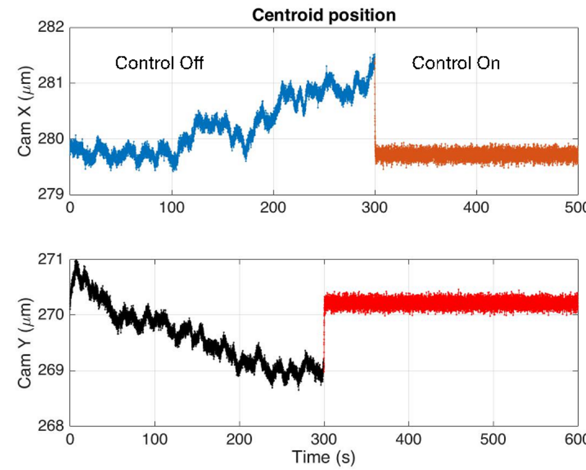


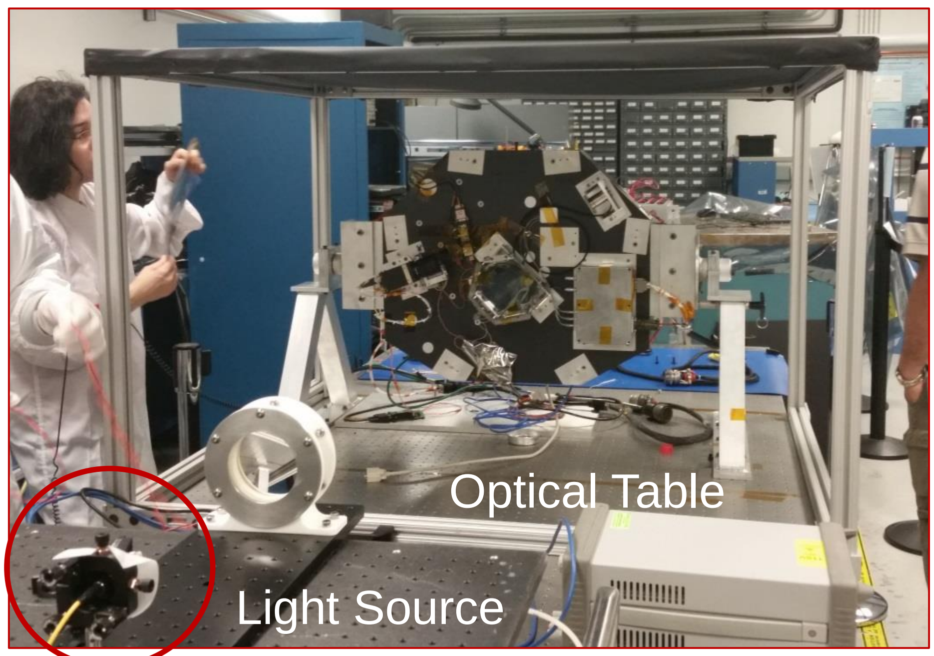
STABLE Predicted Performance

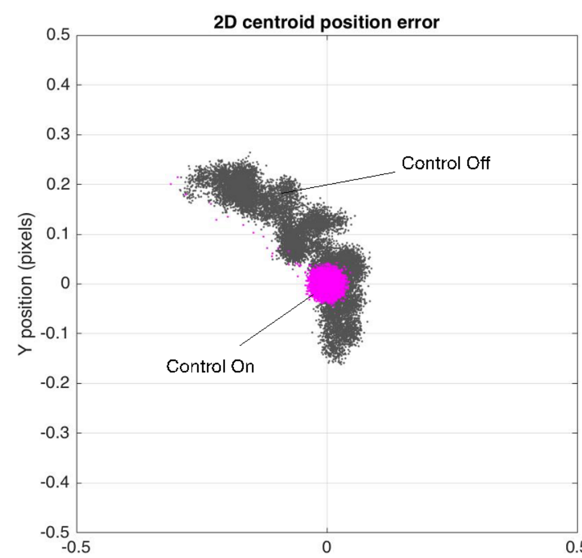
	STR-THR-OPT Optical Performance at Float	CDH-FSW-PCS High-Bandwidth Loop
Key Perf. Spec	Strehl Ratio: 0.376 to 0.739 Target: 0.6	Pointing Stability: 94.5 mas Target: 100 mas
Major Sensitivities	• PM-to-SM spacing (1:36 change in spacing to back focus distance) • Gravity sag at high elevation angles causes worse performance • Large thermal range (80 degC) leads to spread of Strehl	• ADC noise / effective bits (12 effective bits instead of 14 led to ~30 mas of pointing stability hit) • Acquisition and centroiding are sensitive to high noise levels

Ambient Lab Disturbance Environment Test



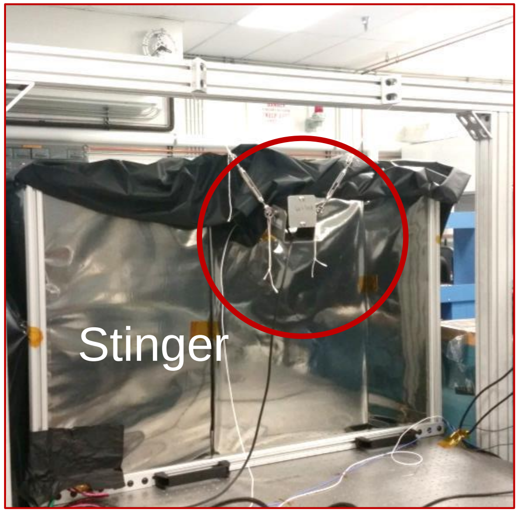


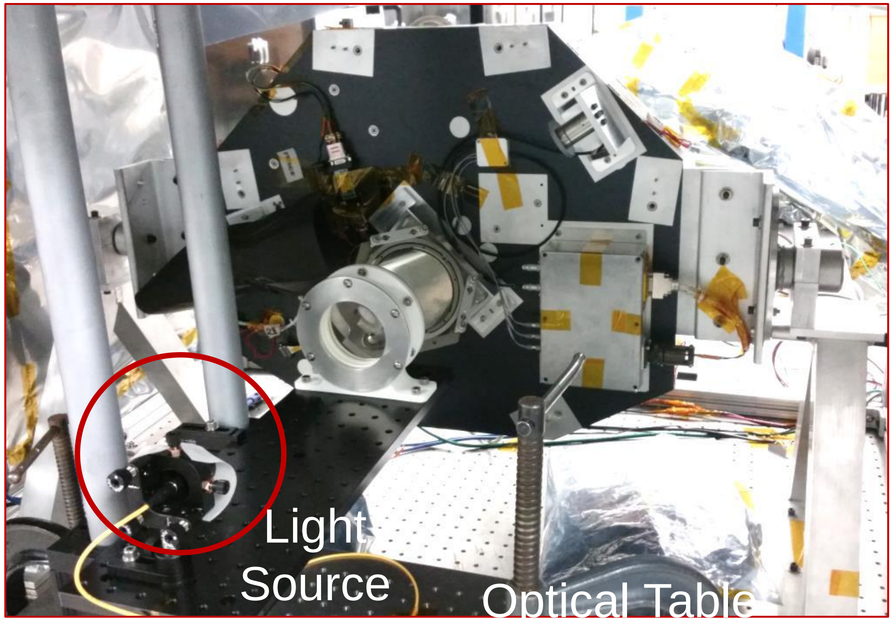


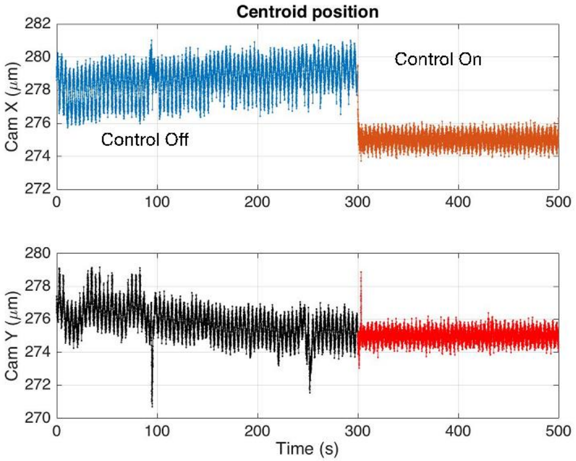


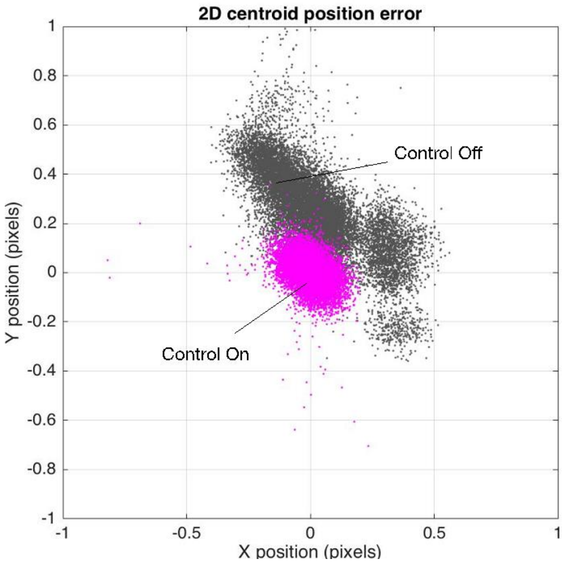
0.13 as = 1 pixel

Stinger @0.25 Hz Disturbance Environment Test





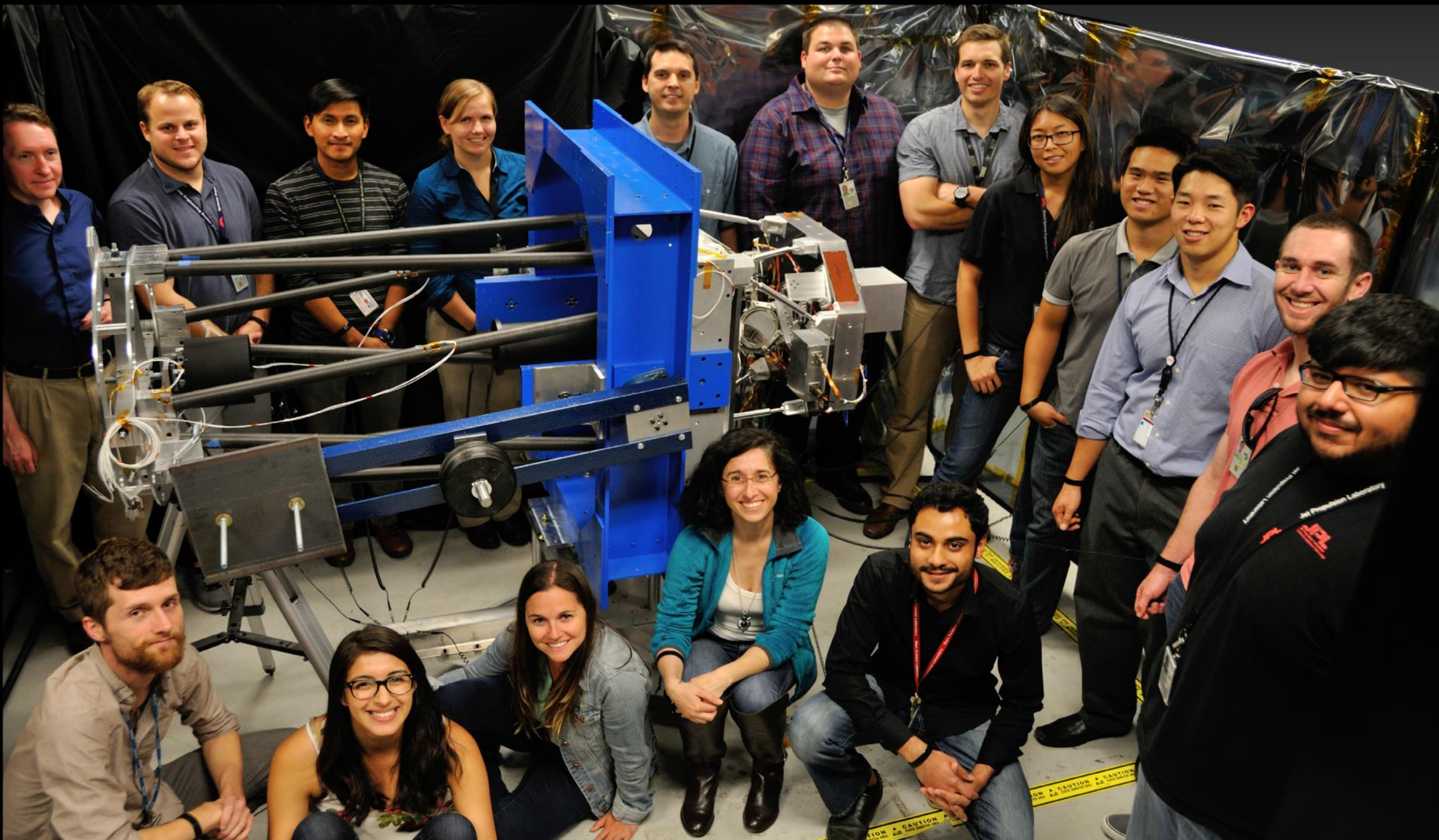




0.13 as = 1 pixel

Conclusions

- STABLE tackles sub arcsecond pointing stability
- Major challenges
  - Large variation in predicted thermal environment
  - Implementation of high bandwidth control loop
- STABLE can achieve 0.945 arc second [over 60 sec, 1σ]
- STABLE was tested in a lab environment


Jet Propulsion Laboratory
CAUTION

EXTRA MATERIAL

BIT/STABLE as a Stepping Stone

POINTING

Fine pointing technology: Enables high precision pointing

High Altitude Balloons: Enable near-space environmental conditions

PLATFORM

BIT-STABLE

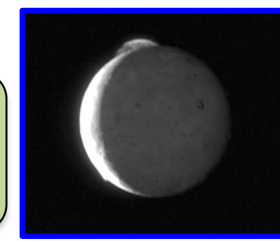
Facilitates

Weak lensing and study of dark matter and dark energy

Study of galaxy formation

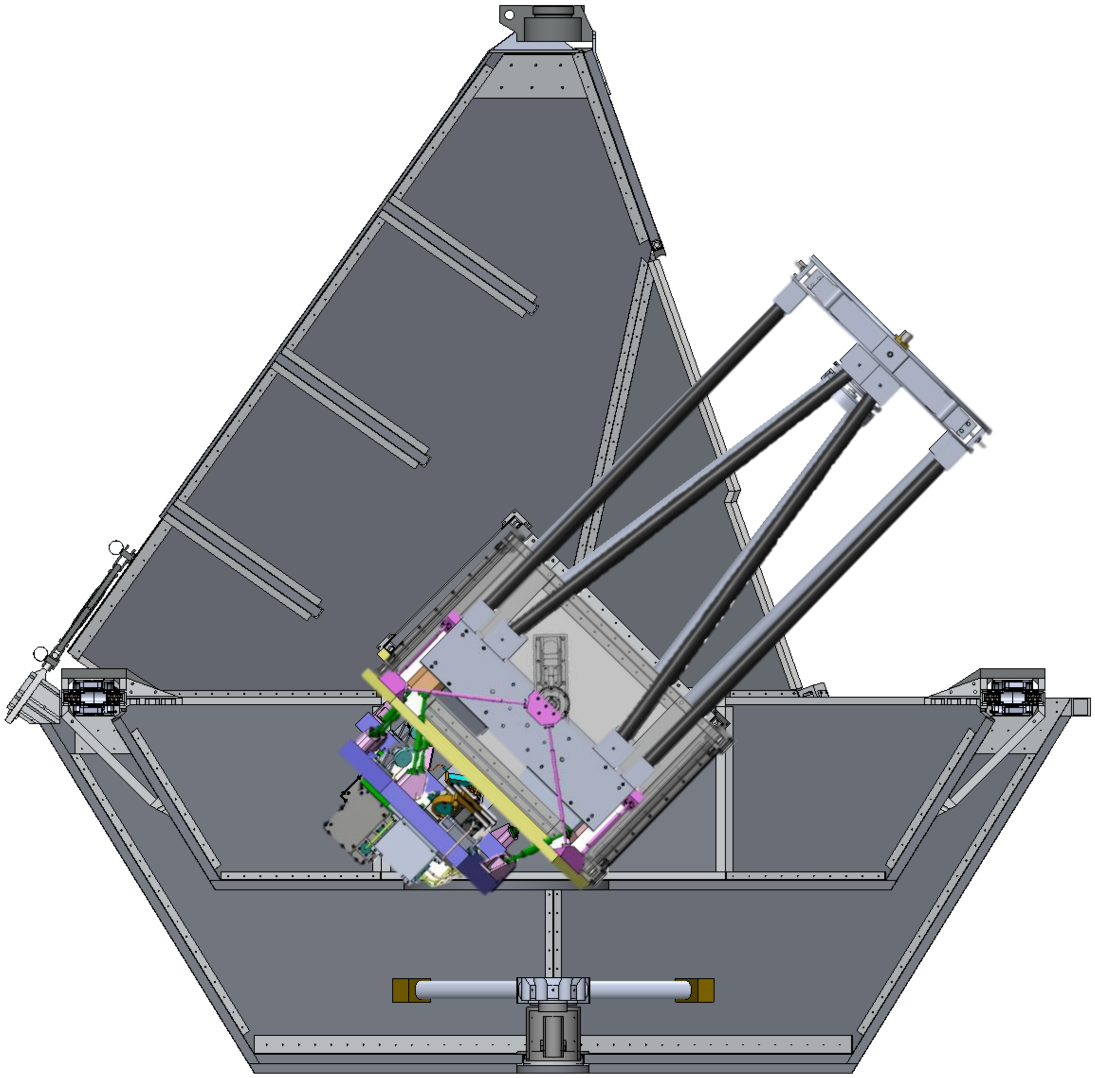
Exo-planet exploration, coronagraphs

Planetary Science

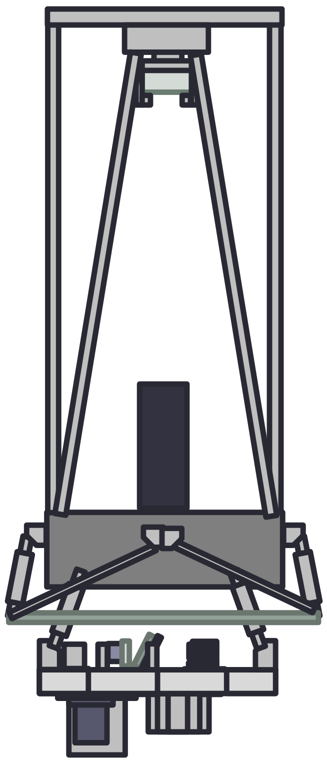


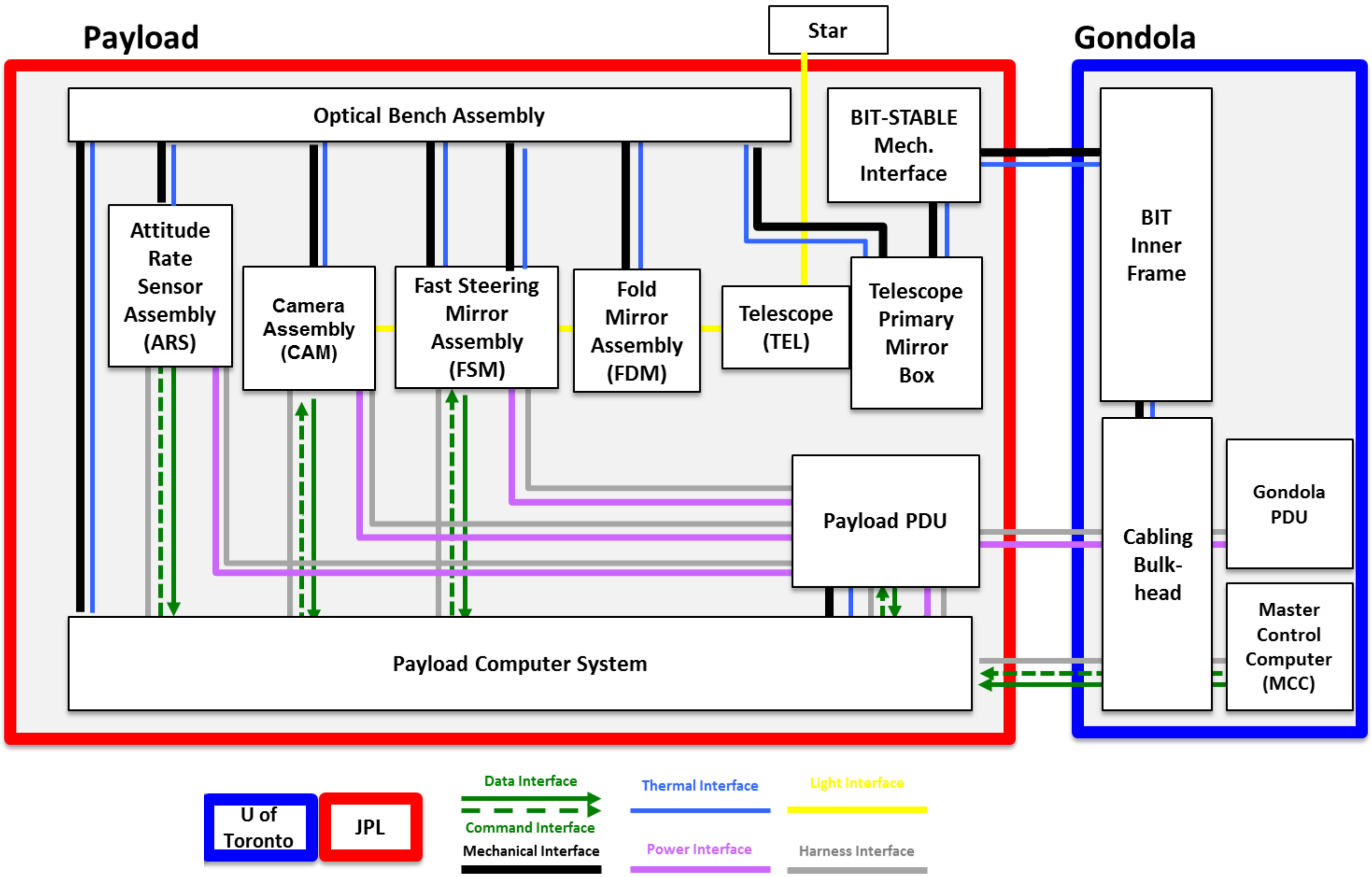
- BIT-STABLE will develop and demonstrate the fine instrument pointing capability

STABLE Payload

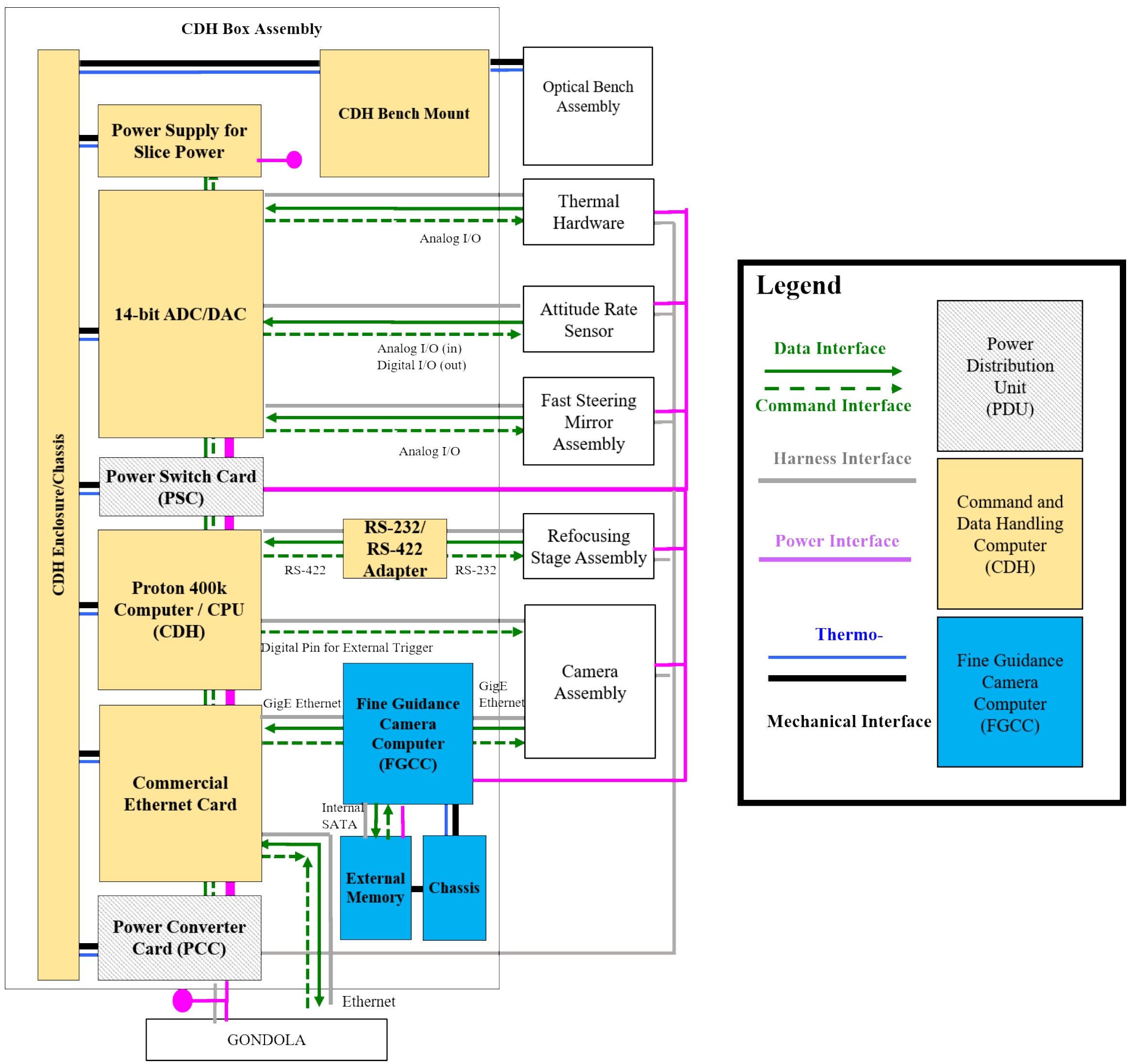


STABLE Payload

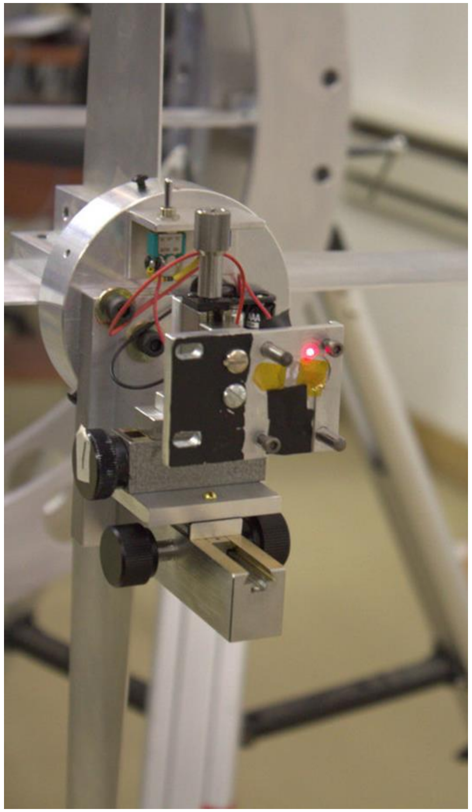
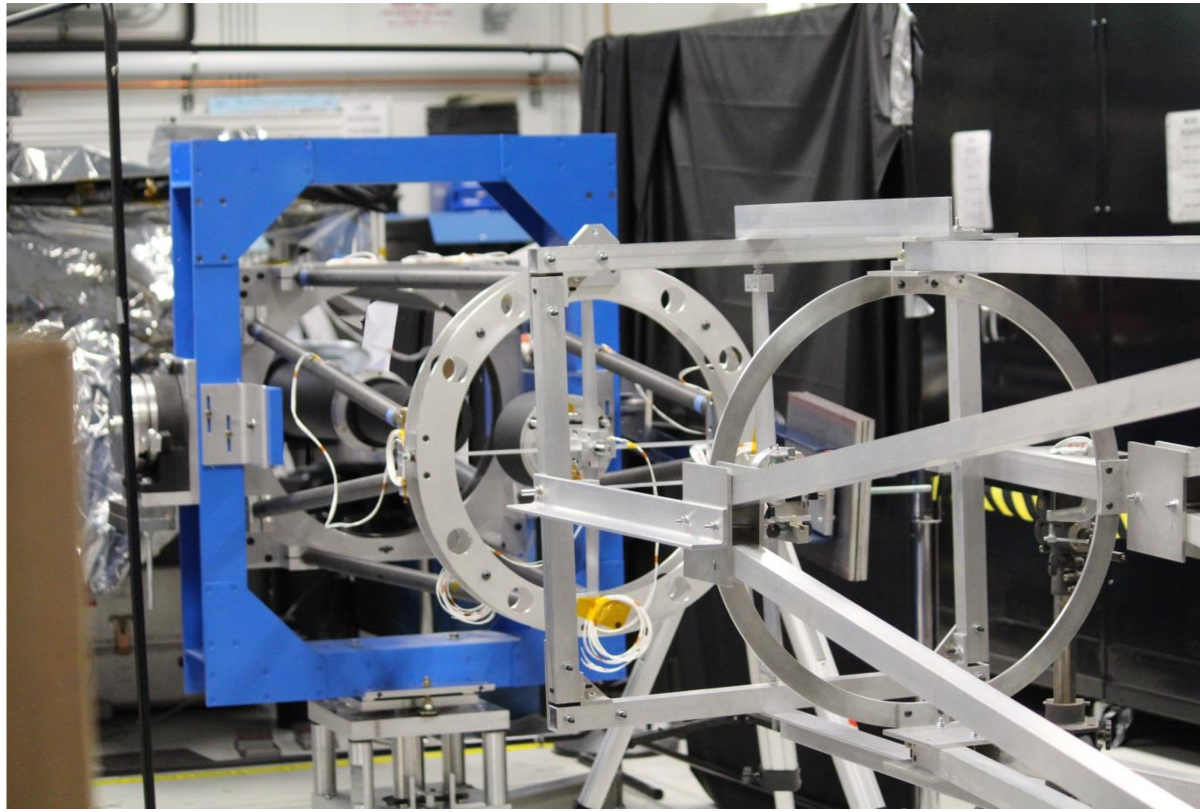
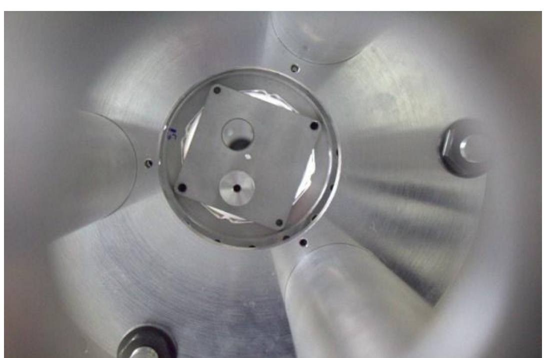




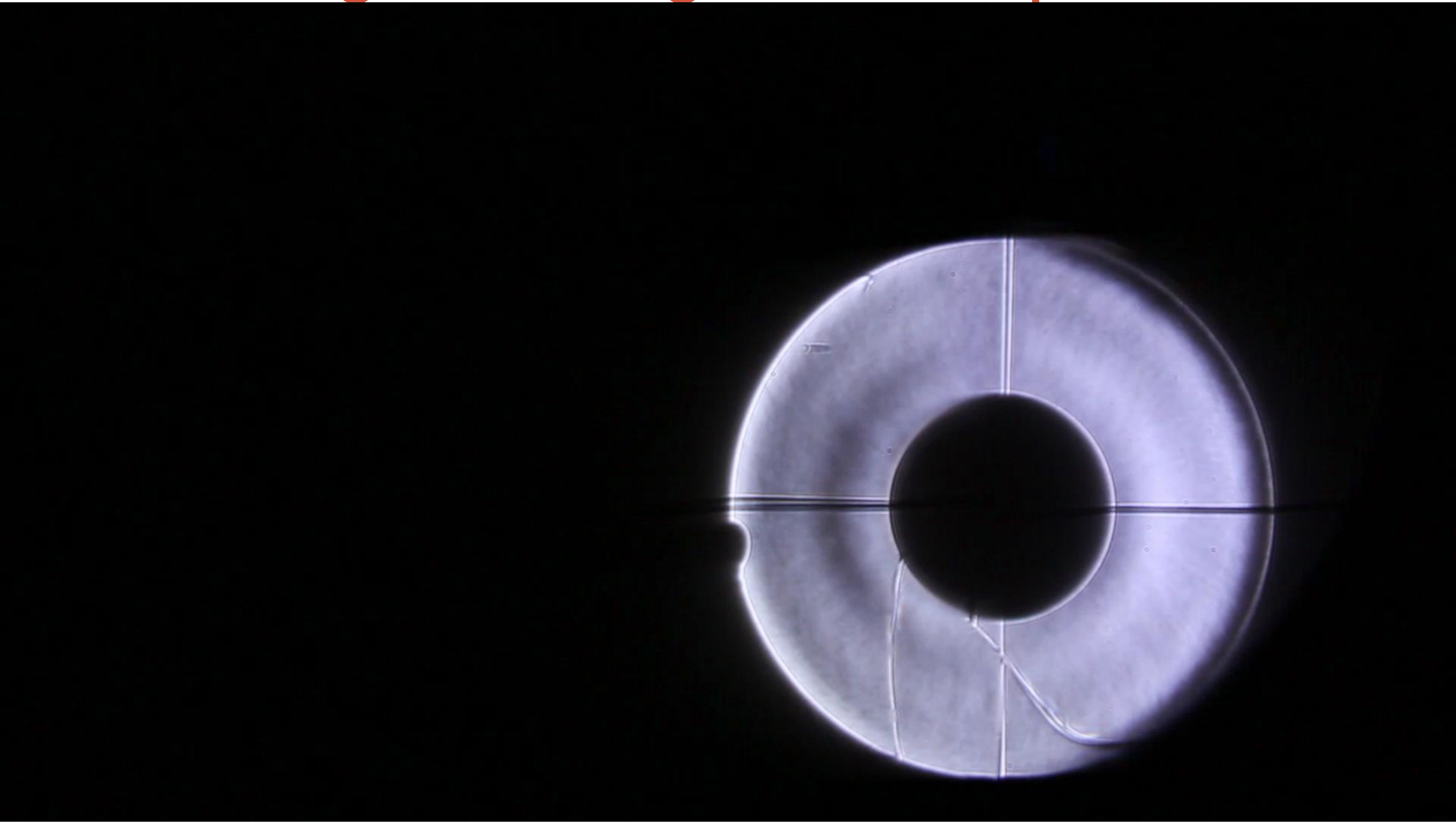
STABLE CDH Diagram



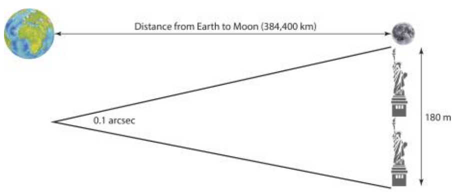
Key I&T Activities: Telescope Alignment

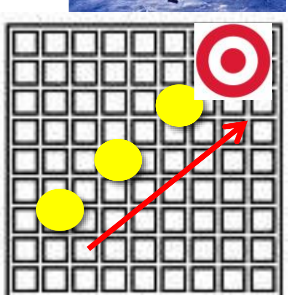
First Light Through Telescope at JPL



STABLE Objectives



$$\mathrm{SNR} = \frac{P_{\mathrm{signal}}}{P_{\mathrm{noise}}}$$

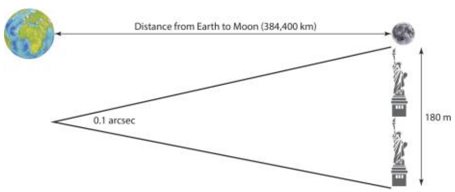


- Design to prove 0.1 arcsec stability for at least 60 seconds
  - 1-σ each axis
  - given coarse-stage pointing to within 2 arc sec 1-σ for at least 120 seconds.
- Use a point source of light
- Use light within the 400-900 nm band
- With SNR less than or equal to 25
- On a balloon-borne platform above an altitude of 25 km.

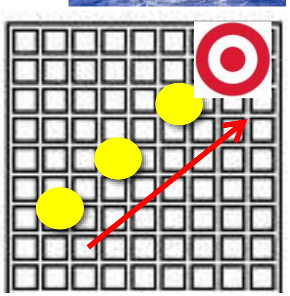
Minimum Success

- Closed loop tracking of target in lab environment

STABLE L1s today



$$\text{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}}$$



Design to prove 0.1 arcsec stability for at least 60 seconds

- ✓ 1-σ each axis
- ✓ given coarse-stage pointing to within 2 arc sec 1-σ for at least 120 seconds.

✓ Use a point source of light

✓ Use light within the 400-900 nm band

✓ With SNR less than or equal to 25

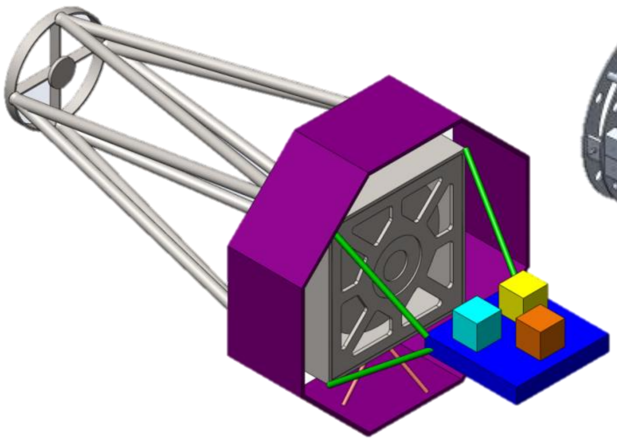
✗ On a balloon-borne platform above an altitude of 25 km.

Minimum Success

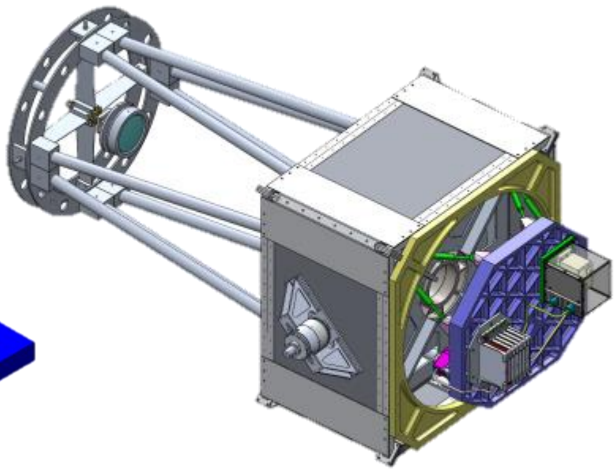
✓ Closed loop tracking of target in lab environment

STABLE Throughout the Years

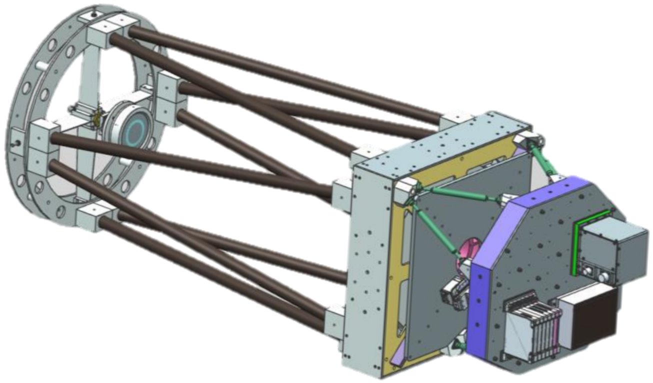
At PMSR, Feb 2013



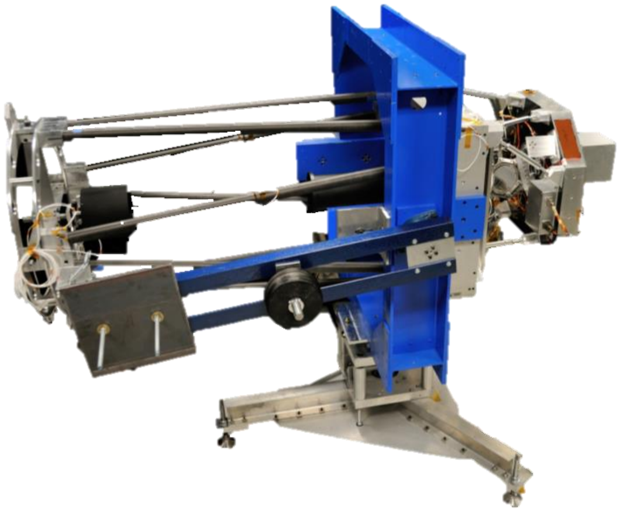
At PDR, Nov 2013



At CDR, Aug 2014

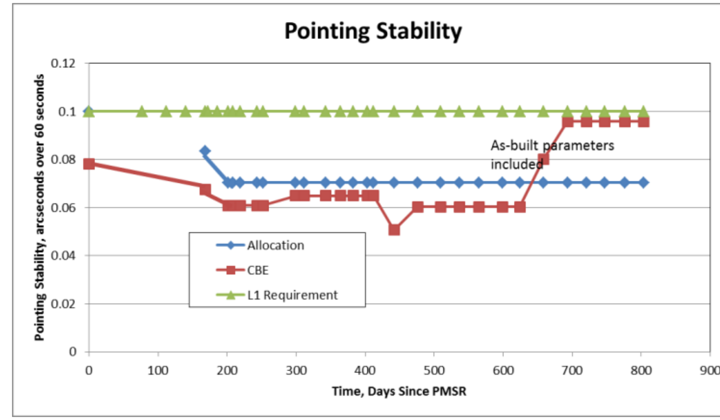


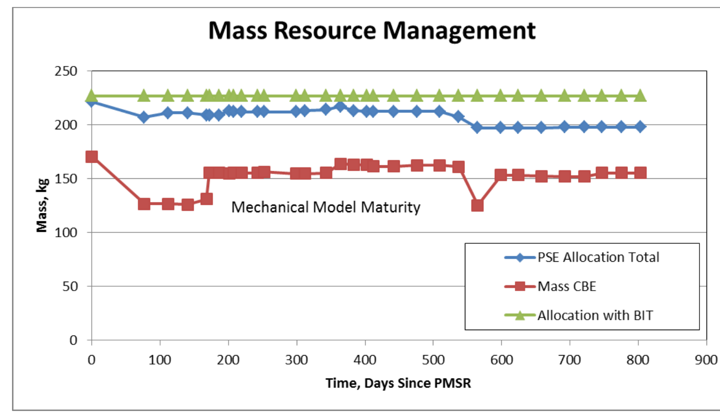
At Payload I&T, Apr 2015

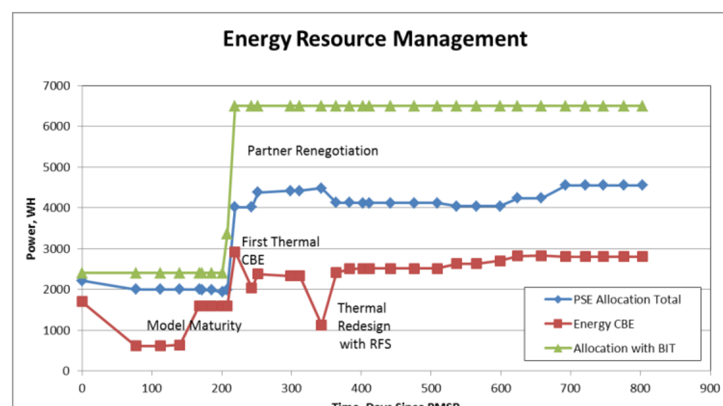


Technical Resources

Resource		Value
Pointing	Allocation	100 mas
	CBE	94.5 mas
Mass	Allocation	227 kg
	CBE	155.2 kg
Energy	Allocation	6500 W-hr
	CBE	2804 W-hr
Peak Power	Allocation	1600 W
	CBE	695 W
Strehl Ratio	Requirement	> 0.6
	CBE	0.631 (nom)
Data Storage	Requirement	<120 GB
	CBE	58 GB
CPU Utilization	Requirement	<100%
	CBE	76.4%







Summary of Full STOP Analysis

Flight Conditions	Strehl Ratio	Error RMS (mas)	
		Tip	Tilt
Case 3 = Nominal Beginning of Night @ 25 deg elevation angle	0.733	92.1	87.7
Case 1 = Nominal Beginning of Night @ 40 deg elevation angle	0.631	94.5	89.4
Case 2 = Nominal Beginning of Night @ 55 deg elevation angle	0.474		
Case 12 = Nominal End of Night @ 25 deg elevation angle	0.694	92.0	87.7
Case 10 = Nominal End of Night @ 40 deg elevation angle	0.573	92.6	87.4
Case 11 = Nominal End of Night @ 55 deg elevation angle	0.444		
Case 6 = Worst Case Hot @ 25 deg elevation angle	0.739	93.7	89.2
Case 4 = Worst Case Hot @ 40 deg elevation angle	0.65	90.9	86.2
Case 5 = Worst Case Hot @ 55 deg elevation angle	0.492	92.0	86.0
Case 9 = Worst Case Cold @ 25 deg elevation angle	0.647	93.5	88.9
Case 7 = Worst Case Cold @ 40 deg elevation angle	0.528	91.6	86.5
Case 8 = Worst Case Cold @ 55 deg elevation angle	0.376	93.8	84.0

Analysis shows that STABLE would meet its L1 objectives

STABLE Error Budget